8.0 REMEDIAL ACTION AND LONG-TERM MONITORING

This chapter provides a recommended approach to developing an effective monitoring plan at contaminated sediment sites. A monitoring plan is recommended for all types of sediment remedies, both during and after remedial action. Monitoring should be conducted at most contaminated sediment sites for a variety of reasons, including: 1) to assess compliance with design and performance standards; 2) to assess short-term remedy performance and effectiveness in meeting sediment cleanup levels; and/or 3) to evaluate long-term remedy effectiveness in achieving remedial action objectives (RAOs) and in reducing human health and/or environmental risk. In addition, monitoring data are usually needed to complete the five-year review process where a review is conducted.

A fully successful sediment remedy typically is one where the selected sediment chemical or biological cleanup levels have been met and maintained over time, and where all relevant risks have been reduced to acceptable levels based on the anticipated future uses of the water body and the goals and objectives stated in the record of decision (ROD). Due to the significant post-remedial residual contamination at some sites, or the inability to control all sources of contamination to the water body, reaching sediment or biota levels resulting in unlimited exposure and unrestricted use may take many years if not decades. Where appropriate, several interim measures of remedy effectiveness should be evaluated at most sites in addition to the key measure of long-term risk reduction. Highlight 8-1 presents four measures that should be considered for all Superfund sediment sites where the remedy includes active remediation such as dredging, excavation, and/or capping. At sites where achieving protection relies upon institutional controls (ICs) such as fish consumption advisories and/or on monitored natural recovery (MNR), only measures 2 and 4would typically apply. A monitoring plan that addresses the appropriate measures generally should be developed and implemented at every sediment site. The term "remedy effectiveness" as used in Highlight 8-1 of this guidance addresses the potential role of monitoring in measuring progress, not as one of the nine criteria provided in National Oil and Hazardous Substances Pollution Contingency Plan (NCP) to evaluate alternatives.

Highlight 8-1: Sample Measures of Sediment Remedy Effectiveness

<u>Interim Measures:</u>

1 - Short-term remedy performance (e.g., Have the sediment cleanup levels been achieved? Was the cap placed as intended?)

2 - Long-term remedy performance (e.g., Have the sediment cleanup levels been reached and maintained for at least five years, and thereafter as appropriate? Has the cap withstood significant erosion?)

3 - Short-term risk reduction (e.g., Do data demonstrate or at least suggest a reduction in fish tissue levels, a decrease in benthic toxicity, or an increase in species diversity or other community indices after five years?)

<u>Key Measure:</u>

4 - Long-term risk reduction (e.g, Have the remediation goals in fish tissue been reached or has ecological recovery been accomplished?)

For Fund-lead sites subject to a state cost share, it may be necessary to distinguish monitoring that is part of the remedial action phase of the remedy from monitoring that is associated with the operation and maintenance (O&M) phase of the remedy. Distinguishing these two monitoring activities is a site-specific decision. Project managers may find it useful to refer to Chapter 3, Section 3.5.2, Operation and Maintenance Costs, for suggestions about what types of activities are frequently associated with long-term O&M as compared to similar activities typically conducted during the remedial action.

This chapter is based in part on the framework presented in the U.S. Environmental Protection Agency's (EPA's) new "Monitoring Guidance," Office of Solid Waste and Emergency Response (OSWER) Directive 9355.4-28, *Guidance for Monitoring at Hazardous Waste Sites: Framework for Monitoring Plan Development and Implementation* (U.S. EPA 2004c). This chapter presents more specific guidance for monitoring of sediment sites; however, many technical details are outside the scope of this chapter. More specific guidance on particular monitoring topics is under development by EPA to assist project managers. In addition, the "triad approach" to systematic planning, dynamic work plans and real-time measurement technologies may have strategies that can be fruitfully applied to sediment site monitoring (see http://www.epa.gov/tio/triad).

8.1 INTRODUCTION

As described in EPA's Monitoring Guidance (U.S. EPA 2004c), monitoring may be viewed as the collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective. Monitoring should include the collection of field data (i.e., chemical, physical, and/or biological) over a sufficient period of time and frequency to determine the status at a particular point in time and/or trend over a period of time in a particular environmental parameter or characteristic, relative to clearly defined management objectives. The data, methods, and endpoints should be directly related to the RAOs and cleanup levels or remediation goals for the site.

Environmental sampling and analysis is typically conducted during all phases of the Superfund process to address various questions. By the time a project manager is implementing a remedial action or writing a monitoring plan, a considerable amount of baseline site data should have been collected during the remedial investigation or site characterization phase. In the site characterization phase, sampling is performed to determine the nature and extent of contamination, to develop the information necessary to assess risks to human health and the environment, and to assess the feasibility of remedial alternatives. During site characterization, the project manager should anticipate expected post-remedy monitoring needs to ensure that adequate baseline data are collected to allow comparisons to future data sets. Monitoring plans should also be designed to allow comparison of results with model predictions that supported remedy selection.

Project managers should ensure that agreements with contractors or responsible parties concerning remedial design and remedial action include requirements for development of an appropriate monitoring plan. The need for environmental monitoring and how the data will be used to measure performance against cleanup levels and RAOs should be considered in the ROD and discussed further early in the remedial design process. Where ICs are part of the remedy, this discussion should also include implementation and, where appropriate, monitoring plans for those controls. Having an early discussion of the monitoring needs as they relate to any engineering performance standards for the particular remedies should allow the project manager sufficient time to resolve logistical or other implementation issues long before the monitoring program is put in place. This discussion during remedial design is also important to determine whether sufficient baseline data have been collected so that both the remedial action and long-term monitoring data can be easily compared to pre-remedy conditions.

At sediment sites, it is also frequently necessary to continue collecting background data from upstream or other reference areas away from the direct influence of the site. This can be especially important where there are uncertainties or potentially changing conditions in background areas, for example, where upstream urban storm water runoff or other possible continuing sources of contamination could impact a remedy.

During the remedial design phase, it is also important to develop a clear understanding of how the monitoring data will be used in the post-remediation decision process, and to ensure that reviews of the monitoring results are conducted in a timely fashion so additional actions can be taken when necessary. In this way, the monitoring data should become a key element of the decision process both in terms of whether the cleanup levels and RAOs are being met and whether additional management actions are warranted.

Highlight 8-2 lists some key questions the project manager should answer before developing a monitoring plan.

Highlight 8-2: Key Questions For Environmental Monitoring

- What is the purpose of the monitoring?
- Are detection limits adequate to meet the purpose of the monitoring?
- Are there likely to be other factors, such as non site-related releases, besides the cleanup that will influence the monitoring results, and are these well understood?
- How often should monitoring take place, and how long should it continue?
- Can the monitoring results be readily placed into searchable, electronic databases and made available to the project team and others?
- Is it clear who is responsible for reviewing the monitoring data and what the triggers are for identifying important trends (positive or negative) in the results?
- What are the most appropriate methods for analyzing the monitoring data? Should these be based on statistical tests or other quantitative analysis? Will there be sufficient data to support these statistical measures?
- Is there agreement on what actions will be taken based on the results of the monitoring data?
- How will the results be communicated to the public, and who is responsible for doing this?

Although sediment sites vary widely in size and complexity, monitoring typically requires a higher degree of planning than at some other types of sites for the following reasons:

- Sediment sites often involve more than one affected medium (e.g., sediment, surface water, biota, floodplain soils, and ground water) and multiple contaminants of concern;
- Contaminants at sediment sites are often from a variety of sources, some of which may be outside of the site in question;

- Sediment sites may require monitoring over large areas and in a variety of physical and ecological settings;

- Spatial and temporal variabilities of aquatic sediment and biota can be great; and

- Risk goals, for sites with bioaccumulative contaminants, generally relate to contaminants in biota and the relationship between contaminant levels in sediment and biota is frequently complex.

An especially important issue for project managers at large sites with more than one response action is the need to monitor both the effectiveness of individual sediment actions and the ability of achieving overall site RAOs. Frequently, the monitoring parameters at large sites are different. For example, where contaminants from multiple sources are indistinguishable, it may be necessary to use unique parameters for monitoring effectiveness of individual actions. However, it also may be very important to monitor parameters (i.e., some fish species), which may be responding to multiple sources or areas of a site.

8.2 SIX RECOMMENDED STEPS FOR SITE MONITORING

When developing a monitoring plan, it is important to review the ROD and supporting documents for the site. The ROD generally should contain numerical cleanup levels and/or action levels for sediment and sometimes for other media, and narrative RAOs that relate more directly to reducing risk. Generally, these form the basis of the monitoring plan. RODs or other site documents may also contain specific performance criteria or objectives for the short-term and long-term performance of the remedy that should be incorporated into the monitoring plan.

EPA's Monitoring Guidance (U.S. EPA 2004c) describes six key steps that are recommended in developing and implementing a monitoring plan. These steps are listed in Highlight 8-3 and explained briefly along with sediment site examples in the following text. This guidance was developed for use at all hazardous waste sites, not just Superfund sites, and therefore, uses the term "site activity" to apply to implementation of removal actions, remedial actions, ICs, or habitat mitigation.

<u>Step 1. Identify Monitoring Plan Objectives</u>

Generally, the most important element in developing an effective monitoring plan is for the project manager to identify clear and specific monitoring objectives. Identifying appropriate monitoring objectives normally includes examining the intended outcomes of the action and the methods used to achieve that outcome at the site. Inadequate or vague monitoring objectives can lead to uncertainty about why the monitoring is being conducted and how the data will be used. Furthermore, funding for monitoring is often limited. Specifying objectives can help to focus the experimental design and ensure that the most useful information is collected. When identifying monitoring objectives other than those already established in decision or enforcement documents, the project manager should involve participants from all concerned stakeholders (e.g., public, natural resource trustees, state agencies, potentially responsible parties).

Highlight 8-3: Recommended Six-Step Process for Developing and Implementing a Monitoring Plan

Step 1. Identify Monitoring Plan Objectives

- Evaluate the site activity
  - Identify the activity objectives
  - Identify the activity endpoints
  - Identify the activity mode of action
- Identify monitoring objectives
- Obtain stakeholder input

Step 2. Develop Monitoring Plan Hypotheses

- Develop monitoring conceptual models
- Develop monitoring hypotheses and questions

Step 3. Formulate Monitoring Decision Rules

Step 4. Design the Monitoring Plan

- Identify data needs
- Determine monitoring plan boundaries
- Identify data collection methods
- Identify data analysis methods
- Finalize the decision rules
- Prepare monitoring quality assurance project plans (QAPPs)

Step 5. Conduct Monitoring Analyses and Characterize Results

- Conduct data collection and analysis
- Evaluate results per the monitoring of data quality objectives (DQOs), developed in Steps 1-4, and revise data collection and analysis as necessary
- Characterize analytical results and evaluate relative to the decision rules

Step 6. Establish the Management Decision

- Monitoring results support the decision rule for site activity success
  - Conclude the site activity and monitoring
- Monitoring results do not support the decision rule for site activity success but are trending toward support
  - Continue the site activity and monitoring
- Monitoring results do not support the decision rule and are not trending toward support
  - Conduct causative factor and uncertainty analysis
  - Revise site activity and/or monitoring plan and implement

Source: U.S. EPA 2004c

Physical, chemical, and/or biological endpoints should be identified to help evaluate each monitoring objective. In general, physical and chemical endpoints are less costly and more easily measured and interpreted than biological endpoints and, therefore, may be more appropriate where quick decisions are needed. However, the ability of physical and chemical endpoints to quantify changes in ecological risk reliably may be less direct than biological measurements, for example where risk is due to direct contact with multiple contaminants. In this case, toxicity tests or bioassessments may provide an integrated measurement of the cumulative effects of all contaminants and, therefore, can be a better assessment of ecological risks in some situations. Conversely, where the primary risk is due to humans and wildlife eating fish, chemical endpoints in fish may be most appropriate.

When identifying appropriate endpoints, it is important for the project manager to ensure that the measure employed matches the time frame established for the criteria. For example, acute toxicity tests quantify short-term effects on an organism; therefore, this type of test may be appropriate for operational monitoring (e.g., monitoring during remedial dredging), where it can be performed in a short period of time. Other biological endpoints, such as changes in species diversity, typically occur over long periods of time and may be more appropriate for use in a long-term monitoring program designed to look at ecological recovery. Although no single endpoint can quantify all possible risks, a combination of physical, chemical, and biological endpoints usually provides the best overall approach for measuring risk reduction.

> **Example:** In the ROD, EPA established a RAO of reducing polychlorinated biphenyl (PCB) concentrations in fish tissue to levels that would eliminate the need for a fish consumption advisory for PCBs (for this site, 0.05 ppm). To achieve this objective, EPA selected a cleanup level of 0.5 ppm total PCBs in sediment. The short-term objective of the monitoring program is to monitor PCB concentrations in sediment until the cleanup level is met and the long-term objective of the monitoring program is to monitor PCB concentrations in fish tissue until the RAO is met.

<u>Step 2. Develop Monitoring Plan Hypotheses</u>

Typically, monitoring hypotheses represent statements and/or questions about the relationship between a site activity, such as sediment remediation, and one or more expected outcomes (U.S. EPA 2004c). The development of the monitoring hypotheses is analogous to the problem formulation step (Step 1) of the DQO process (U.S. EPA 2000a). The monitoring hypothesis may be generally stated as "The site activity has been successful in reaching its stated goals and objectives," or in question form, as "Has the site activity reached its stated goals and objectives?" As described in EPA's Monitoring Guidance (U.S. EPA 2004c), the concept of a monitoring conceptual model may be helpful in identifying and organizing appropriate hypotheses. This model, frequently a flow chart or graphical display, consists of a series of working hypotheses that identify the relationships between site activities and expected outcomes.

> **Example hypotheses:** The PCB concentration in sediment has reached the cleanup level of 0.5 ppm. The PCB concentration in fish tissue has reached the remedial goal of 0.05 ppm.

<u>Step 3. Formulate Monitoring Decision Rules</u>

Once monitoring objectives and hypotheses are agreed upon and stated explicitly, the next step should be to identify specific decision rules that will be used to assess whether the objectives are met. A decision rule is normally an "if... then..." statement that defines the conditions that would cause the decision maker to choose an action. In a monitoring plan, the decision rules should establish criteria for continuing, stopping, or modifying the monitoring or for taking an additional response action. Four main elements of a decision rule usually are: 1) the parameter of interest; 2) the expected outcome of the remedial action; 3) an action level, the basis on which a monitoring decision will be made; and 4) alternative actions, the monitoring decision choices for the specified action (U.S. EPA 2004c).

Another factor the project manager should consider when developing decision rules is the time frame under which they will operate. For example, when dredging highly contaminated sediment, a real-time monitoring program could be established to analyze water samples before proceeding with the next day's dredging. In contrast, the time frame required to assess a long-term monitoring objective (e.g., to lower fish tissue concentrations) would be longer. In either case, the time frame should be explicitly stated and understood by all the participants.

> **Examples:** A decision rule could be established to require certain actions if suspended sediment or contaminant concentration in the surface water due to releases from dredging exceed certain criteria. A decision rule could be established to assess whether the sediment cleanup level of 0.5 ppm PCBs has been reached, defined as an average of 0.5 ppm PCBs in each of ten grids over the site. A decision rule could be established to assess whether progress is being made toward the remedial action objective of reduced PCB concentrations in fish tissue by establishing an interim goal of achieving 0.8 ppm in fish tissue within five years, after which monitoring frequency will be revisited. PCB concentrations in fish species "A" will be measured on a specific frequency (e.g., annually) that is commensurate with the relevant species' uptake and depuration rates.

<u>Step 4. Design the Monitoring Plan</u>

The fourth recommended step for the project manager is to identify the monitoring design for collecting the necessary data. Design considerations include identifying data needs; determining monitoring boundaries (frequency, location, duration); identifying data collection methods; and identifying data analysis methods, including uncertainty analysis. EPA recommends that a systematic planning approach be used to develop acceptance or performance criteria for all environmental data collection and use. The Agency's DQO process is a planning approach normally appropriate for sediment sites (U.S. EPA 2000a). Quality assurance project plans (QAPPs) or their equivalent are also recommended for environmental data collection and use.

The spatial and temporal aspects of a monitoring plan typically define where and when to collect samples. In general, sampling locations should be based on the areal extent and magnitude of the contaminated sediment and the propensity for the contaminants to move, either through transport (e.g., remediation, natural events) or through the food chain. Generally, the more dynamic the conditions, the more frequently sampling is necessary to represent conditions accurately. However, a less costly alternative can be to use data endpoints which respond to cumulative, longer-term conditions, where appropriate. Additional factors that should be considered in establishing sampling locations include locations of baseline or pre-remediation sampling stations and spatial gradients in concentration. For example, generally greater sample density is needed where concentration gradients are high.

Selecting a statistical approach to use in evaluating the data is another important aspect of the monitoring program design. Data are sometimes collected in a manner that is incompatible with or insufficient for the statistical tests used to analyze the data. Although the amount of data needed to compare point-in-time data may be less than that needed to reliably establish a trend in data, both types of analyses may be needed to draw conclusions reliably. Especially for critical decisions, project managers should seek expert advice in order to design a sampling program that will yield statistically defensible results. One potential method, power analysis, is described in *Biostatistical Analysis* (Zar 1999).

Another crucial element of developing a monitoring plan typically is cost. Generally, it is more cost-effective to collect less data, providing they are the "correct" or most useful data than it is to collect more of the "wrong" data. Following the key steps outlined in this guidance to design a monitoring plan should help project managers determine what are the "correct" data. Project managers may also find it useful to consider the use of indicator or surrogate parameters that correlate with those of primary interest, as a supplement to primary parameters that are especially costly or problematic to collect.

Finally, this step of monitoring plan development should ensure mechanisms are in place for modifying the plan based on new information.

> **Example:** From the remedial investigation data, we know that smallmouth bass spend most of their time in the contaminated area and spawn in late spring. The proposed sampling plan would consist of overlaying an unbiased sampling grid onto a map of the contaminated area of River X as well as in the areas upstream and downstream of the site. It is decided that 30 four-year old female bass will be collected in the early spring, before spawning, in each of these areas. A power analysis on baseline data indicated 20 fish would allow the project team to discern a 0.5 ppm or greater change in tissue concentration with 0.25 ppm confidence intervals (90 percent). However, given cost considerations, only ten samples will be analyzed immediately and the other 20 archived for further analyses pending the results.

<u>Step 5. Conduct Monitoring Analyses and Characterize Results</u>

The next recommended step in developing a monitoring plan includes data collection and analysis, evaluating analytical results, and addressing data deviations from the monitoring DQOs. At this point, the project manager should evaluate the data with regard to the monitoring hypotheses, the DQOs, and the monitoring decision rules developed in previous steps. At this step, the project manager should implement decision rules that may call for continuing, stopping, or modifying the monitoring or for taking additional action at the site.

In addition, the project manager should communicate data and results to the appropriate audiences. Frequently, the importance of communicating the results is underestimated. Because information is often provided to individuals with various levels of technical expertise, it should be comprehensible at multiple levels of understanding. Complex scientific data are not often easily understood by those without a technical background, and ineffective data communication often leads to skepticism about the conclusions. Therefore, it is important that the project manager consider the audience and present results in multiple formats. To those less familiar with the technical presentation of data, information can be presented in easily understood visual formats [e.g., geographic information system (GIS)]. This approach maximizes the effective dissemination of information to the greatest number of individuals, thus increasing the probability that the conclusions will be understood and believed.

> **Example:** At this point, three years of fish tissue data have been collected, analyzed, and validated. The decision criterion for this monitoring objective was to reduce the PCB

concentrations in fish tissue to 0.8 ppm within five years. The data show that after the third year, fish tissue concentrations have decreased significantly but the averages are still above 0.8 ppm; however, the higher levels are restricted to a relatively small area and most fish are below 0.8 ppm. The results are summarized and presented to the stakeholders. Due to the declining trend, the decision is made that the monitoring objective is expected to be met within five years and the fourth year monitoring effort can be skipped.

Step 6. Establish the Management Decision

The final step of a monitoring plan should be an extension of Step 5, to evaluate monitoring results and uncertainties and come to a decision regarding any changes in site activities or changes in the monitoring plans that may be appropriate at this time. Developing contingency plans in advance for actions that may need to be taken in response to monitoring results is recommended.

Example: Due to the declining trend, the decision is made that the monitoring objective is expected to be met within five years and the fourth year monitoring effort can be skipped.

An outline of the six steps and suggested subparts is shown in Highlight 8-2. It should be noted that the following outline essentially follows EPA's DQO process, with modification for ease of application to a contaminated sediment site. Project managers should refer to the DQO process guidance (U.S. EPA 2000a) to supplement this outline when preparing a sediment site monitoring program.

8.3 POTENTIAL MONITORING TECHNIQUES

This section provides a brief overview of the types of monitoring techniques and data endpoints that the project manager could consider when developing a monitoring plan. Selection of endpoints depends on the requirements in the decision and/or enforcement documents, as well as more general considerations related to the cleanup methods selected and the phase of the operation, as discussed in previous sections. For complex sites, frequently a combination of physical, chemical, and biological methods and a tiered monitoring plan (Highlight 8-3), is the best approach to determine whether a sediment remedy is meeting sediment cleanup levels, RAOs or goals, and associated performance criteria both during remedial action and in the long term. Monitoring, sampling, and analysis methods are being constantly improved based on research and increased field experience. Project managers should watch for new methods and, where they offer additional accuracy or lower cost but also allow for data to be compared to existing data, consider using them.

Generally, physical and chemical endpoints are easier to measure and interpret than biological endpoints. In the case of human health risk, chemical measurements are commonly used to assess risk. In contrast, measurement of the biological community is a direct but often complex measurement for monitoring changes in ecological risk. Caged organisms (e.g., *Macoma*, or mussels) at the site over a defined time frame can identify changes in bioavailable concentrations of many contaminants. Collection of fish and tissue analysis can address both human health and ecological response of the system, if both needs are considered during design of the sampling and analysis plan. The project manager should refer to EPA's Office of Water *Methods for Collection, Storage, and Manipulation of Sediments for Chemical* *and Toxicological Analyses* (U.S. EPA 2001k) and *Managing and Sampling and Analyzing Contaminants in Fish and Shellfish* (U.S. EPA 2000h) for more detailed information.

Biological endpoints (e.g., toxicity tests) typically provide an integrated measurement of the cumulative effects of all contaminants. When using biological endpoints, it is important for the project manager to ensure the biological test employed fits the intended criteria. For example, acute toxicity tests are designed to quantify short-term effects on an organism; therefore, this type of test may be appropriate when monitoring for short-term impacts of a remedy. However, for toxicity tests to be useful, it is important to have demonstrated during site characterization a significant relationship between the contaminant and toxicity. Other biological endpoints, such as changes in species diversity, typically occur over long periods of time and may be more appropriate for use in a long-term monitoring program designed to look at ecological recovery. While no single endpoint can quantify all possible risks, project managers should consider a combination of physical, chemical, and biological endpoints to provide the best overall approach for assessing the long-term effectiveness of a remedial action in achieving the RAOs.

8.3.1 Physical Measurements

Physical testing at a site may include measurements of erosion and/or deposition of sediment, ground water advective flow, particle size, surface water flow rates, and sediment homogeneity/heterogeneity. Potential types of physical data and their uses include the following:

- *Sediment Geophysical Properties:* Uses include fate and transport modeling, determination of contaminant bioavailability, and habitat characteristics of post-cleanup sediment surface;

- *Water Column Physical Measurements (e.g., turbidity, total suspended solids):* Uses include monitoring the amount of sediment resuspended during dredging and during placement of in-situ caps;

- *Bathymetry Data:* Uses include evaluating post-capping or post-dredging bottom elevations for comparison to design specifications, and evaluating sediment stability during natural recovery;

- *Side Scan Sonar Data:* Uses include remote sensing to monitor the distribution of sediment types and bedforms;

- *Settlement Plate Data:* Uses include monitoring changes in cap thickness over time and measuring cap consolidation;

- *Sediment Profile Camera Data:* Uses include monitoring of changes in thin layering within sediment profiles, sediment grain sizes, bioturbation and oxidation depths, and the presence of gas bubbles; and

- *Subbottom Profiler Data:* Uses include remote sensing measurement of changes in sediment surface and subsurface layers, bioturbation and oxidation depths, and presence of gas bubbles.

8.3.2 Chemical Measurements

Chemical testing may include sediment chemistry (both the upper biological surficial zone and/or deeper sediment), evaluating biodegradation, contaminant partitioning to the pore water, and concentrations of total organic carbon. Potential sampling tools and environmental monitoring methods used in support of chemical measurements include the following:

- *Sediment Grab Samplers:* Uses include collection of samples for measurement of surface sediment chemistry;

- *Coring Devices (e.g., vibracore, gravity piston, or drop tube samplers):* Uses include obtaining a vertical profile of sediment chemistry, or detection of contaminant movement through a cap or through a layer of naturally deposited clean sediment;

- *Direct Water Column Measurements (probes):* Uses include measurement of parameters such as pH and dissolved oxygen in the water column;

- *Surface Water Samplers:* Uses include measurement of chemical concentrations (dissolved and particulate) in water or contaminant releases to the water column during construction;

- *Semi-Permeable Membrane Devices:* Uses include measurement of dissolved contaminants at the sediment-water interface; and

- *Seepage Meters:* Uses include measurement of contaminant flux into the water column.

8.3.3 Biological Measurements

Biological testing can include toxicity bioassays, examining changes in the biological assemblages at sites, either to document problems or evaluate restoration efforts, and/or determining toxicant bioaccumulation and food chain effects. Potential types of biological monitoring data and their uses also include the following:

- *Benthic Community Analysis:* Uses include evaluation of population size and diversity, and monitoring of recovery following remediation;

- *Toxicity Testing:* Uses include measurement of acute and long-term lethal or sublethal effects of contaminants on organisms to help establish a protective range of remediation goals;

- *Tissue Sampling:* Uses include measurement of bioaccumulation, modeling trophic transfer potential, and estimating food web effects;

- *Caged Fish/Invertebrate Studies:* Uses include monitoring change in uptake of contaminants by biota from the sediment or water column to measure the effect of the remedy on bioaccumulation rates; and

- Sediment Profile Camera Studies: Uses include indirect measurement of macroinvertebrate recolonization, for example, measuring population density of polychaetes by counting the number of burrow tubes per linear centimeter along the sediment-water interface.

The interpretation of fish tissue results and their relationship to sediment contaminant levels can be especially complex. Potential complications may relate to questions of home range, lipid content, age, feeding regime, contaminant excretion rates, and other factors. Especially at low contaminant concentrations, these variabilities can make understanding the relationship between trends in sediment and biota concentrations especially difficult.

Fact sheets are under development at EPA concerning biological monitoring at sediment sites, including:

- An approach for using biological measures to evaluate the short-term and long-term remedial effects at Superfund sites; and

- An approach for using bioaccumulation information from biota sediment accumulation factors (BSAFs) and food chain models to assess ecological risks and to develop sediment remediation goals.

8.4 REMEDY-SPECIFIC MONITORING APPROACHES

The following sections discuss monitoring issues particular to MNR, in-situ capping, and dredging or excavation. Many sediment remedies involve a combination of cleanup methods, and for these remedies, the monitoring plan will likely include a combination of techniques to measure short- and long-term success. At many sediment sites, monitoring of source control actions is an important first step.

8.4.1 Monitoring Natural Recovery

Monitoring of natural recovery remedies often tests the hypothesis that natural processes are continuing to operate at a rate that is expected to reduce contaminant concentrations in appropriate media such as biota to an acceptable level in a reasonable time frame. Other measures of reduced risk may also be appropriate for a site. In most cases, monitoring involves measuring natural processes indirectly or measuring the effects of those processes. As a sound strategy for monitoring natural recovery the project manager should consider the following:

- Monitoring direct or indirect measures of natural processes (e.g., sediment accumulation rates, degradation products, sediment and contaminant transport);

- Monitoring contaminant levels in surface sediment, surface water, and biota; and

- Monitoring measures of biota recovery (e.g., sediment toxicity, benthic community size and/or diversity).

When monitoring natural recovery, it is usually important to monitor sediment, surface water, and biota. The water column is typically important because it integrates the flux of contaminants from sediment and is not typically subject to as large a spatial variability as sediment. Biota monitoring is important because it is frequently directly related to risk.

Monitoring continued effectiveness of source control actions can be especially important at MNR sites. Depending on the quality of existing trend data, MNR remedies may require more intensive monitoring early in the recovery period, which may be relaxed if predicted recovery rates are being attained. Also, there may be a need to collect additional data after an intensive disturbance event.

EPA's Science Advisory Board (SAB), in its May 2001 report, *Monitored Natural Attenuation: USEPA Research Program - An EPA Science Advisory Board Review* (U.S. EPA 2001j), Section 3.4, Summary of Major Research Recommendations, indicates the need for the development of additional monitoring methods to quantify attenuation mechanisms, contaminated sediment transport processes, and bioaccumulation to support footprint documentation and analysis of permanence. EPA is aware of these research needs and plans to address some of these topics in ongoing and future work.

For areas that may be subject to sediment disruption, the project manager should conduct more extensive monitoring when specified disruptive events (e.g., storms or flow stages of a specified recurrence interval or magnitude) occur to evaluate whether buried contaminated sediment has been disturbed or transported and the extent of contaminant release contaminants and increased exposure. The project manager should design the monitoring plan to handle the relatively quick turnaround times needed to effectively monitor disruptive events. However, interpretation of these data in terms of increased risk should take into account the length of time organisms may be exposed to higher levels of contaminant concentrations.

The project manager should include periodic comparisons of monitoring data to rates of recovery expected for the site in an MNR monitoring program. Where predictions were based on modeling, the project manager should make monitoring results available to the modeling team or other researchers to conduct field validation of the model. Where contingency remedies or triggers for additional work are part of a remedy decision, the project manager should design the monitoring plan to help determine whether those triggers are met. For example, a contingency for additional evaluation or additional work may be triggered by an increasing or insufficiently decreasing trend in contaminant concentrations in sediment, surface water, or biota at specified locations. Where contingencies for additional work are triggered, the project manager may need to include measures such as additional source control, additional ICs, the placement of a thin layer of clean sediment to enhance natural recovery, or an active cleanup (i.e., dredging or capping).

Following attainment of cleanup levels and remedial action objectives, monitoring may still be needed at some MNR sites. For sites where natural recovery is based on burial with clean sediment, continued monitoring may be necessary to assess whether buried contaminants remain buried after an intensive disturbance event. This monitoring should continue until the project team has reasonable confidence in the continued effectiveness of the remedy.

8.4.2 Monitoring In-Situ Capping

Remedial action monitoring for capping generally includes monitoring of construction and placement, and of cap performance during an initial period. It may also include monitoring of broader RAOs such as recovery of the benthic community or of contaminant levels in fish. Long-term monitoring for capping generally includes continued periodic monitoring of cap performance and maintenance activities, and continued monitoring of RAOs. In some cases (e.g., Fund-lead sites) it may be necessary to distinguish monitoring that is part of remedial action from monitoring that is part of O&M. This should be a site-specific decision. Highlight 8-4 lists sample elements of monitoring an in-situ cap. It is important to note that not all of these elements may be needed for every cap. In general, cap monitoring should be designed so that elements can be phased back or eliminated if the remedy is performing as expected and there has been no large-scale disturbance of the cap.

As shown in Highlight 8-4, a variety of monitoring equipment and methods can be used for capping projects during both remedial action and long-term monitoring. The extent of any necessary monitoring should be a site-specific decision and also may depend on decision and enforcement document requirements. In general, bathymetric surveys to determine cap thickness and stability over time, sediment core chemistry (including surface sediment and upper portion of cap) to confirm physical and chemical isolation and test for recontamination, and some form of biological monitoring are useful for most capping projects. Specialized equipment, such as seepage meters, diffusion samplers (e.g., peepers and semi-permeable membrane devices), sediment profile cameras, sediment traps, or use of caged organisms, may also be useful in some cases.

Construction monitoring for capping normally is designed to measure whether design plans and specifications are followed in the placement of the cap and to monitor the extent of any contaminant releases during cap placement. During construction, monitoring results can be used to identify modifications to design or construction techniques needed to meet unavoidable field constraints. Construction monitoring frequently includes interim and post-construction cap material placement surveys. Appropriate methods for monitoring cap placement include bathymetric surveys, sediment cores, sediment profiling camera, and chemical resuspension monitoring for contaminants. For some sites, visual observation in shallow waters or surface visual aids, such as viewing tube or diver observations, can also be useful.

Biological monitoring in the initial period following cap construction may include monitoring of the benthic community that may recolonize the capped site and the bioturbation behavior of bottom-dwelling organisms. Where contaminants are bioaccumulative, fish or other biota edible tissue or whole body monitoring are also likely to be needed.

Long-term monitoring of in-situ capping sites typically is important to ensure that the cap is not being eroded or significantly compromised (e.g., penetrated by submerged aquatic vegetation, ground water recharge, or bioturbation) and that chemical contaminant fluxes that ultimately do move through the cap to surface water do so at the low projected rate and concentration. It may be also desirable to include ongoing monitoring for recontamination of the cap surface and non-capped areas from other sources.

Highlight 8-4: Sample Cap Monitoring Phases and Elements

Monitoring Phase	Element	Component	Analysis	Frequency/Location
Cap Construction	Cap material quality	Cap material sampling	Physical properties	5% of loads
	Cap thickness and areal extent	Bathymetry Subbottom profile	Thickness of cap layers Areal extent of cap	Baseline Initial placement Final surveys over entire area
		Sediment profile camera	Thickness of cap layers	Baseline Initial placement Defined grid for remaining cells
		Cores	Layer thickness and physical properties Chemical properties for baseline	Defined grid
	Sediment resuspension	Plume tracking Acoustic doppler current profile (ADCP) Water column samples	Suspended sediment Water column chemistry	5% of load placements
	Sediment displacement	Sediment samples	Chemical properties of sediment	Sediment bed near cap boundaries
Cap Performance	Recolonization	Sediment profile camera Benthic community analysis	Layer thickness Re-colonization, population size, and diversity	Defined grid - frequency determined by local information about recolonization rates
	Physical isolation	Subbottom profile Bathymetry	Layer thickness	Annual checks in some cases Surveys over entire area every five years, modify as needed
	Chemical isolation	Cores Peepers, seepage meters, if needed	Physical properties Sediment chemistry, pore water chemistry	Defined grid every five years, modify as needed
Severe Event Response	Cap integrity	Subbottom profile Sediment profile camera Cores		Following major storms or earthquakes

For areas that may be subject to cap disruption, more extensive monitoring should be triggered when specified disruptive events (e.g., storms, flow stages, or earthquakes of a specified recurrence interval or magnitude) occur, to evaluate whether the cap was disturbed and whether any disturbance caused a significant release of contaminants and increased risk. Additional monitoring for the effects of tidal and wave pumping and boat propeller wash is also recommended where these are expected to be important factors. In general, the project manager should monitor cap integrity both routinely and following storm/flood events that approach the design storm magnitude envisioned by the cap's engineers. As for other types of sediment remedies, the project manager should design the monitoring plan to handle the relatively quick turnaround times needed to effectively monitor disruptive events.

Cap maintenance is generally limited to the repair and replenishment of the erosion protection layer in potentially high erosion areas where this is necessary. Project managers should consider the ability to detect and respond quickly to a loss of the erosion protection layer when evaluating a capping alternative. Seasonal limitations, such as ice formation or closure of navigation structures (locks), can affect the ability to monitor and maintain in-situ caps and should be accounted for in monitoring plans.

Capping remedies frequently include provisions for actions to be taken in the case that one or more cap functions are not being met. Options for modifying the cap design may or may not be available. If monitoring shows that the stabilization component is being eroded by events of lesser magnitude than planned, or the erosive energy at the capping site was underestimated, then eroded material can be replaced with more erosion-resistant cap material. If monitoring indicates that bottom-dwelling organisms are penetrating the cap and causing unacceptable releases of contaminants, then project managers should consider placing additional cap material on top of the cap to maintain isolation of the contaminated sediment. These types of management options are usually feasible where additional cap thickness, and the resulting decrease in water depths at the site, does not conflict with other waterway uses. Where a cap has been closely designed to a thickness that will not limit waterway use (i.e., recreational or commercial navigation), the options for modifying a cap design after construction can be limited.

8.4.3 Monitoring Dredging or Excavation

Monitoring for dredging or excavation remedies generally includes construction and operational monitoring of the dredging or excavation, transport, dewatering, any treatment, transport, and any on-site disposal placement. Following dredging or excavation, the residual sediment contamination should also be monitored. Additional monitoring following sediment removal may include monitoring of sediment toxicity or benthic community recovery or, for bioaccumulative contaminants, tissue concentrations in fish or shellfish, as well as continued monitoring of any on-site disposal facilities and monitoring sediment and/or biota for recontamination.

Depending on the levels of contamination and the selected methods of dredging/excavation, transport, treatment or disposal, potential construction and operational monitoring may include the following:

- Surface water monitoring at the dredging site and any in-water disposal sites (e.g., total suspended solids, total and dissolved contaminant concentrations, caged fish toxicity, caged mussel intake);

- Dredging/excavation residual monitoring at the sediment surface to determine whether cleanup levels are met;

- Effluent quality monitoring after sediment dewatering and/or treatment;

- Air monitoring at the dredge, transport, on-site disposal, and treatment sites; and

- On-site disposal monitoring of dredged sediment or treatment residuals.

A thorough monitoring plan will normally enable project managers to make design or construction changes to ensure that the spread of contamination to uncontaminated areas of the water body, sensitive habitats, or adjacent human populations is minimized during dredging, transport, treatment, or disposal. Depending on the contaminants present and their tendency to volatilize or bioaccumulate, the project manager should consider water, air, and biological sampling in the monitoring plan.

Generally, a monitoring plan for dredging should include collecting data to test the effectiveness of silt curtains, dredge operating practices, and any other measures used to control sediment resuspension or sediment or contaminant transport. In most cases the project manager should include sampling upgradient of the dredging operation and both inside and outside of any containment structures. Generally this sampling should also include dissolved compounds in the water column, although in some cases it may be a appropriate to use a tiered approach with analysis of dissolved compounds triggered by exceedances of threshold criteria for total compounds or for suspended solids. Also, where contaminants may be volatile, project managers should consider the need for air sampling. At highly contaminated sites, it may be necessary for the project manager to conduct a pilot study on a small area to determine if the sediment can be removed without causing unacceptable risks to adjacent human populations or adjacent benthic habitat. This information can help to determine what containment barriers or dredging methods work best and what performance standards are achievable at the site. The project manager should compare monitoring results with baseline data for contaminant concentrations in water and, where appropriate, in air. This should ensure that effects due to dredging may be separated and evaluated from natural perturbations caused by tides and storms. The project manager should develop contingency plans to guide changes in operation where performance standards are not met.

Following dredging, it is usually essential for project managers to conduct monitoring to determine whether cleanup levels in sediment are achieved. Initial sampling should be analyzed rapidly, so that contingency actions, such as additional dredging, excavation, or backfilling, can be implemented quickly if cleanup levels have not been met.

Following sediment removal, it is usually necessary for the project manager to conduct long-term monitoring to ensure that the dredged or excavated area is not recontaminated by additional sources or by disturbance of any residuals that remain above cleanup levels. Long-term monitoring is usually necessary to provide data to determine whether RAOs are met, and may be necessary for a period of time following remedial action to provide confidence that the objectives will remain met.

If an in-water or upland disposal facility is constructed on site as part of the remedy, it should also be monitored to ensure that it remains intact and that there are no unacceptable contaminant releases in the long term. Monitoring is recommended to determine whether contaminants are leaking through the bottom or walls of the on-site confined disposal facility (CDF) or landfill, and to determine if any surface cap remains intact to ensure protection from infiltration. Depending on the type of disposal site and the nature of the contamination, long-term disposal site monitoring may include the following:

- Seepage from the CDF containment cells to surrounding surface water;
- Ground water monitoring;
- Surface water runoff monitoring;
- Disposal area cap integrity monitoring; and
- Revegetation or recolonization by plant and animal communities monitoring, and their potential uptake of contaminants.

Highlight 8-5 lists important points to remember related to monitoring sediment sites.

Highlight 8-5: Some Key Points to Remember About Monitoring Sediment Sites

- Presentation of a monitoring plan is important for all types of sediment remedies, both during and following any physical construction, to ensure that exposure pathways and risks have been adequately managed
- Development of monitoring plans should follow a systematic planning process that identifies monitoring objectives, decision criteria, endpoints, and data collection, and data interpretation methods
- Before implementing a remedial action, project managers should determine if data adequate baseline data exists for comparison to future monitoring data and, if not, collect additional data
- Where background conditions may be changing or where uncertainty exists concerning continuing off-site contaminant contributions to a site, it may be necessary to continue collecting data from upstream or other reference areas for comparison to site monitoring data
- Monitoring needs include both monitoring of construction and operation and monitoring intended to measure whether cleanup levels in sediment and remedial action objectives for biota or other media have been met
- Monitoring plans should be designed to evaluate whether performance standards of the remedial action are being met and should be flexible enough to allow revision if operating procedures are revised
- Field measurement methods and quick turnaround analysis methods with real-time feedback are especially useful during capping and dredging operations to identify potential problems which may be corrected as the work progresses
- After completion of remedial action, long-term monitoring should be used to identify recontamination, to assess continued containment of buried or capped contaminants, and to monitor dredging residuals and on-site disposal facilities